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PALISADES, NEW YORK

Technical Report on Seismology No. 30

Bermuda T Phases with Large Continental Paths

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CU- -53-N6 onr 27124 Geol.

Bermuda T Phases with Large Continental Paths

by

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ABSTRACT

A short period arrival on records of the Bermuda-Columbia Seismograph Station is identified as the T phase. The path of propagation consists of land paths up to 51° preceeding 14° of water path. It is shown that the travel time of this phase can be accounted for if the energy travels as the P phase over the land path and the T phase over the ocean path. Background noises in the Sofar channel do arise in some cases from earthquakes as much as several thousand miles inland.

INTRODUCTION

The T phase is a short period phase which travels with the velocity of sound in water. Its duration is from thirty seconds to several minutes and its beginning and ending are gradual. The maximum amplitude is near the midpoint of the signal and the frequency of the T phase is 2 to 6 cps.

While operating the Bermuda-Columbia Seismograph Station, the author observed a short period phase with T characteristics which correlated with earthquakes in South America. Preliminary calculations showed that the travel time could be accounted for by using P travel time from epicenter to the north coast of Puerto Rico and T phase travel time from Puerto Rico to Bermuda.

Tolstoy and Ewing (1950) studied the seismograms of the Fordham, Weston, and Ottawa stations and showed that only the Atlantic earthquakes occurring north of the Dominican Republic produced T phases. They concluded that the Mid-Atlantic Ridge and Azores Plateau would

stop or greatly reduce the amount of energy carried in a T phase from Azores shocks and that T phases from Mid-Atlantic Ridge shocks were not observed because of the small magnitude of the shocks, the ocean bottom topography near the epicenters, and the large angle of incidence at the continental shelf in their path to the station. The T phase at Martinique from earthquakes in Costa Rica was studied by Coulomb and Molard (1952). These T phase paths contain land segments with water on either side and it was concluded that continental propagation of T waves on the periphery of the Carribean did not appear possible as P waves but did appear possible as S waves. Ewing, Press, and Worzel (1952) examined T phases from Pacific earthquakes for which the path was as nearly as possible oceanic and concluded that the T phase is propagated as compressional waves in water. Wadati and Inouye (1953) investigated the T phases of Pacific earthquakes and suggested that the T wave is generated at the ocean bottom near the epicenter by SV and P waves and confirmed the opinion of Ewing, Press and Worzel (1952) that the existence of the steep slope of the sea bottom plays an important part in the entrance into the water.

In the present paper results are presented from an investigation of earthquakes of magnitude greater than 6½ occurring in southern Mexico, Central America and South America since the installation of Benioff short period seismographs on Bermuda in 1951. Selected Benioff short period vertical records from the San Juan station were also used in the investigation. The results show that significant amounts of energy

can be propagated over a path consisting of land from epicenter to the north side of Puerto Rico and water from Puerto Rico to Bermuda.

All epicenter and time data used in the study came from the cards of Preliminary Determination of Epicenter issued by the U. S. Coast and Geodetic Survey, and the travel times of P were obtained from Seismological Tables of Jeffreys and Bullen (1948). The T phases were identified at Bermuda on the records of Benioff short period seismograms recording on 35mm film and on the Sofar geophone recording on photographic paper. The latter instrument has a peak response to waves with frequency of 8 - 12 cps.

DISCUSSION

All earthquakes studied are listed in Table I which gives epicenter data, magnitude, and distance from Bermuda. Throughout the discussion the different earthquakes will be referred to by number. Table II is a summary of travel time data for earthquakes which produced a T phase at Bermuda. The precise ocean path to Bermuda is somewhat uncertain for the earthquakes in Table II. The paths for all these tremors, as seen in Figure I, intersect the steep submarine slope near the Puerto Rico Trough, and only small errors are introduced by taking 14° as the water path. The travel time for this 14° of water was taken as 17m 23s which corresponds to a velocity of 4900 ft/sec.

Table II shows which instruments recorded the T phases and the difference in observed and calculated travel times. The largest differences are those for earthquakes 14 and 22. These two are the smallest of the T phases identified at Bermuda, 14 being the smallest seen on

both geophone and seismograph and PP being identified only on the more sensitive geophone. Even these differences are reasonable in view of the 14° approximation of water path since a small error in water path of 1° would make the calculated total travel time differ by amounts comparable to the difference in observed and calculated times. The possibility of attributing the T phases to other coincidental tremors is slight since for the six earthquakes in Table II either the San Juan records or the Joint Bulletin of Atlantic stations has been examined and San Juan indicates no other possible source of the phase.

The possibility must be noted that some of the earthquakes of Table I could generate a T phase not detected at Bermuda. A small T phase would be detected only on the more sensitive water instrument and the banks near Bermuda shelter this instrument from arrivals from the more westward direction. There is an additional obstacle in the possibility of a T phase being generated by the more westward earthquakes of Table I. Figure II shows a N-S cross-section from Puerto Rico into the ocean. The conditions here are very good for the T phase to enter the water as the T phase. However, moving westward the condition becomes increasingly poor. A glance at a bathymetric chart of the West Indian region shows that there are no submarine slopes comparable to that near Puerto Rico and much of the slope that does exist is sheltered by islands and banks so that there is no good water path to Bermuda.

It is unfortunate that the earthquakes suitable for this discussion produce P phases at San Juan of such magnitude and frequency

that the records are difficult to reproduce. However, close examination of Figures III and IV shows that for earthquakes 9 and 17 the P phase as seen at San Juan is very nearly the same frequency as the T phase at Bermuda, and Figures V - A and V - B show that the San Juan P phase of earthquakes 16 and 18 which did not make T phases are of much lower frequency than the P phase of either 9 or 17. It is also interesting to note by comparing Figures III - A and III - B to Figure VI that the San Juan P phase of the earthquakes of Table II are very similar to the P phase of the local earthquake 24, which gave a T phase at Bermuda. Figure VII of a San Juan P phase from earthquake 15 gives an indication of the magnitude of P necessary at San Juan to give T at Bermuda. The P phase for this earthquake shows a frequency near that of a T phase at Bermuda, but the amplitude is small compared to the P phases of earthquakes which actually gave T at Bermuda. By comparing earthquakes 15, 17 and 21, it can be seen that a deep focus earthquake seems to be a better generator of this T phase. These three tremors are very close to the same distance from Bermuda at very nearly the same azimuth. Their magnitudes differ somewhat, but 21 is perhaps the smallest since the U. S. Coast and Geodetic Survey gives no magnitude number, and yet 15, the only shallow earthquake of the three, is the only one not to give a T phase at Bermuda. It is also noticeable that the two shallow focus earthquakes of Table II are the ones with the largest difference in observed and calculated travel time.

Certainly the magnitude of the earthquake is of importance also in determining whether or not a T phase will be generated, and there

must be ocean bottom topography at some point in the path suitable for T to enter the water. The actual entrance into the water can be explained by the arrival of the P wave at the submarine slope as described by Wadati and Inouye (1953) although in our case the slope is distant from the epicenter by many times the depth of focus.

This investigation bears on the controversy concerning the mode of propagation of the T phase between the ocean and an inland station such as Ottawa. Since the path from the vicinity of Ottawa to Bermuda is much the same as the path of the earthquakes of Table II, earthquakes in the vicinity of Ottawa were studied when Bermuda records were available. The path to Bermuda of earthquake 25 consists of about 8° land and 8° water so that one would expect T about 22h 16m 00s. Bermuda recorded eT at 22h 17m 31s and Tmax at 22h 18m 24s. In comparison to Table II this is a rather large difference in observed and calculated travel time but the same possible errors are present. The data of earthquake 25 suggests that the conditions necessary for the T phase to go from land to water may be much the same as needed to go from water to land.

CONCLUSIONS

The following conclusions are reached in this study of T phases generated by inland earthquakes.

1. The energy travels as P before entering the water. The S phase is not an effective generator of T at the Puerto Rico Scarp.

2. A deep focus earthquake is apparently a better generator of this T phase.

3. Both magnitude and frequency of the P phase are critical in determining whether it will generate a T phase upon its arrival at a steep submarine slope.

4. A T phase will be generated by the arrival of a P phase at a steep submarine slope if the P phase contains energy within the characteristic frequency range of the T phase, and this T phase can be detected at distant stations if there are no obstacles in the path between the submarine slope and the station.

5. The P-T transmission could have been predicted by considerations of resciprocity from earlier observation at inland stations.

6. Earlier work (Ewing, Press and Worzel - 1952) demonstrated the contribution to the background noise in the Sofar channel of earthquakes in or on the periphery of a given ocean basin. It is now seen that distant earthquakes also can contribute.

ACKNOWLEDGEMENTS

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TABLE I

Quake No.	Date	Time at Origin	Epicenter Location Lat.° Long.°	Magnitude	km Depth	in °
1	6 Dec 51	14-29-18	5½N 77½W			29°
2	12 Dec 51	01-37-34	17N 94½W	7	100	30°
3	28 Dec 51	09-20-25	17N 98½W	7¼ - 7½		33°
4	3 Jan 52	10-05-05	16N 99W	6½		35°
5	15 Jan 52	07-00-53	4S 81W			39°
6	14 Feb 52	21-01-37	7½N 76¼W	6 3/4		27°
7	26 Feb 52	11-31-04	14½S 70W	7½	300	47°
8	2 Apr 52	18-34-50	16½N 99½W	6¼ - 6½		34°
9	19 Apr 52	09-58-53	7N 71½W	6 3/4 - 7	60	26°
10	25 Apr 52	06-02-00	8N 83W	6¼ - 6½		29°
11	13 May 52	19-31-45	10½N 85W	6.9	100	29°
12	16 May 52	20-45-40	6½N 79W	6.9 - 6½		29°
13	24 May 52	01-59-05	21½S 71W	6 3/4		53°
14	11 June 52	00-31-32	32S 67½W	7		65°
15	9 July 52	18-15-18	7½N 82W	6½		29°
16	9 Sept 52	12-54-42	9N 84½W	6 3/4 - 7		30°
17	21 Sept 52	02-30-30	22½S 65W	7½	250	54°
18	3 Oct 52	07-36-45	6½N 83W	6½		30°
19	20 Nov 52	15-37-17	12½N 88W	6½ Pas 6 3/4 - 7 Berk	60	29°
20	29 Apr 52	19-42-25	Central Chile	6 Pas		68°
21	9 Mar 52	21-54-30	Northern Chile-Argentina border region		200	55°
22	31 Mar 52	00-50-40	6S 79½W			41°
23	20 Aug 52	08-31-05	off NW coast of Puerto Rico		100	13°
24	2 Oct 52	12-24-42	Off South coast of Puerto Rico			15°
25	14 Oct 52	22-03-41	Southeastern Quebec 48N 70W			16°

TABLE II

Earthquake Number	Observed Travel Time	to Puerto Rico or Slope	Puerto Rico to Bermuda	Jeffreys & Bullen P Travel Time to Puerto Rico	Calculated T travel Time Puerto Rico to Bermuda	Total Calculated Travel Time	Difference in Observed and Calculated Time	Instrument Recording T Phase
7	23m 08s	33°	14°	06m 07s	17m 23s	23m 30s	22s	geo & seismo
9	20m 37s	12°	14°	12m 49s	17m 23s	20m 12s	25s	seismo (no geo record)
14	28m 07s	51°	14°	09m 01s	17m 23s	26m 24s	01m 43s	geo & seismo
17	24m 34s	40°	14°	07m 09s	17m 23s	24m 32s	02s	seismo
21	24m 06s	41°	14°	07m 22s	17m 23s	24m 45s	39s	geo (no seismo record)
22	24m 24s	27°	14°	05m 41s	17m 23s	23m 04s	01m 20s	geo

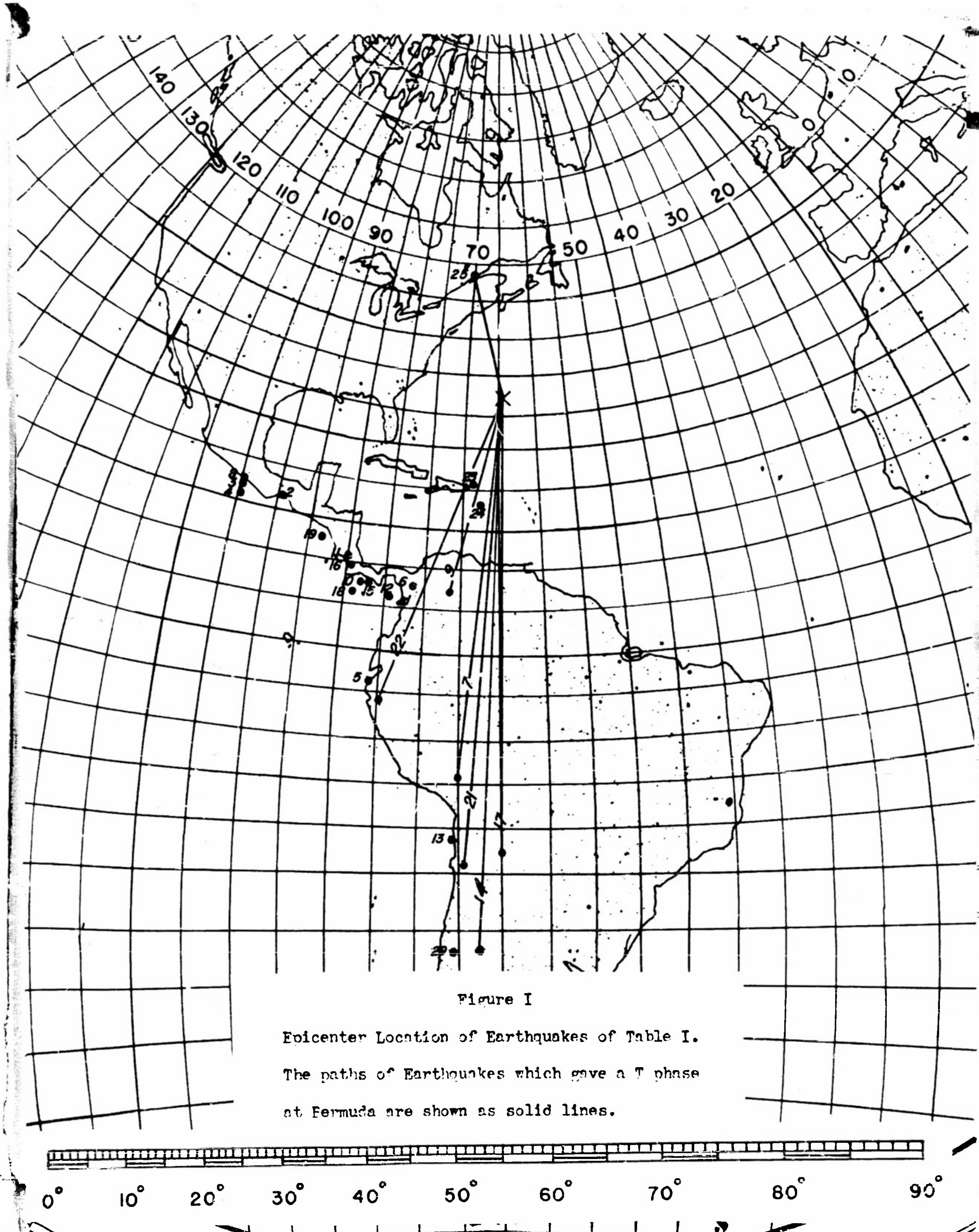


Figure I

Epicenter Location of Earthquakes of Table I.

The paths of Earthquakes which gave a T phase

at Bermuda are shown as solid lines.

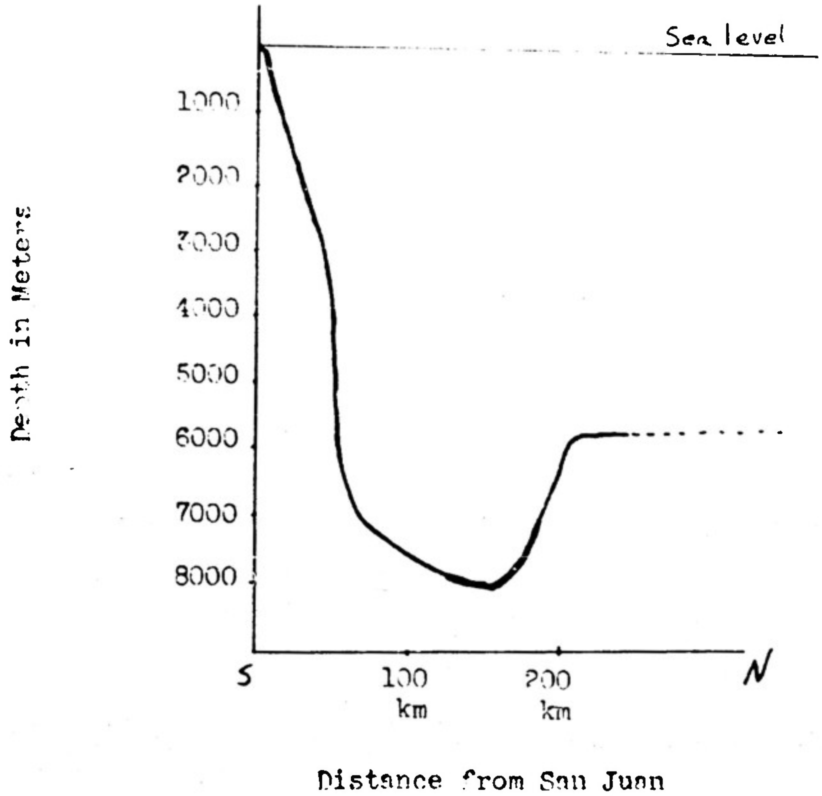


Figure II

N-S Cross section from San Juan across Puerto Rico trough.

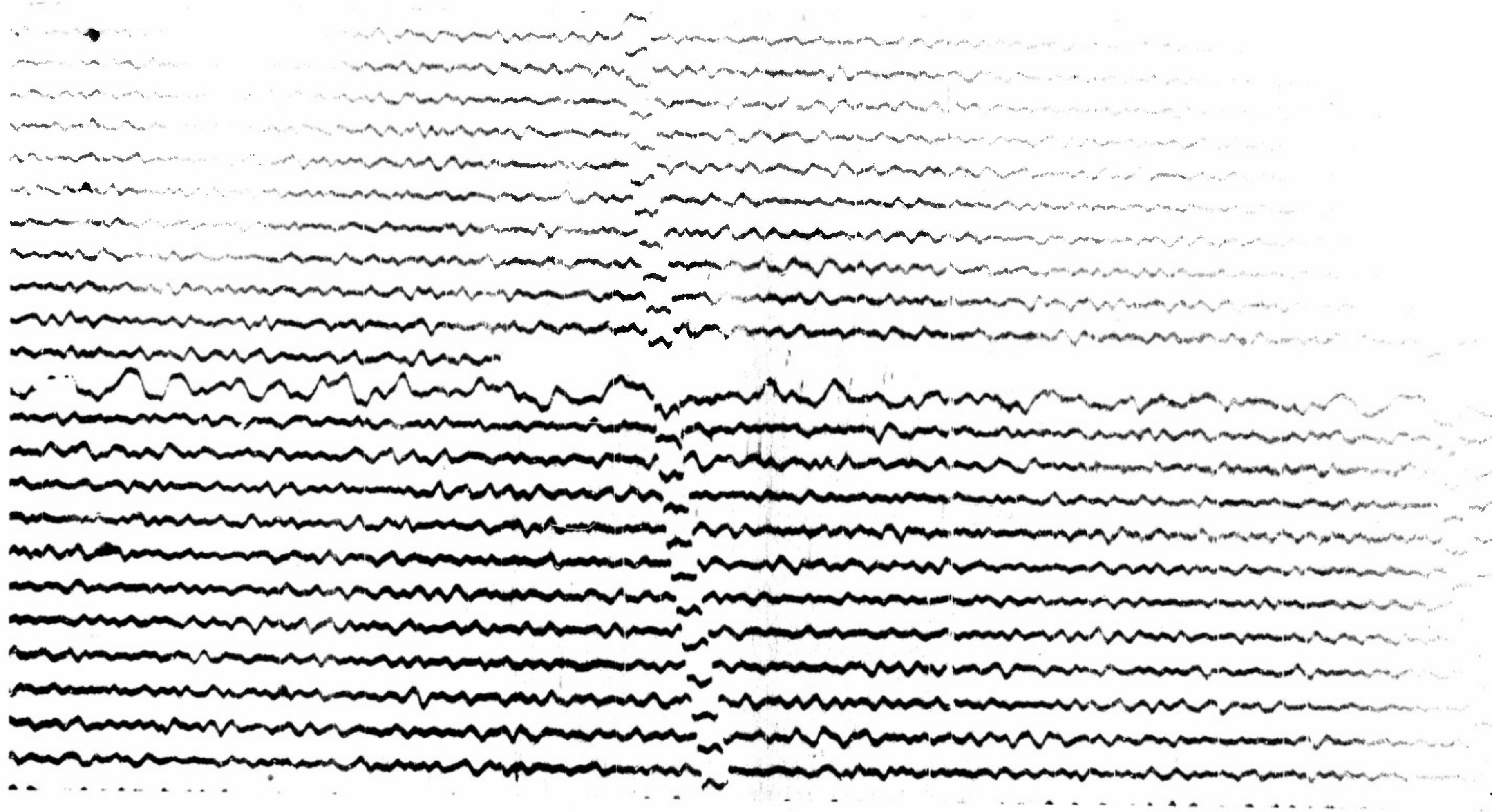


Figure III - A

San Juan P Phase of Earthquake 17

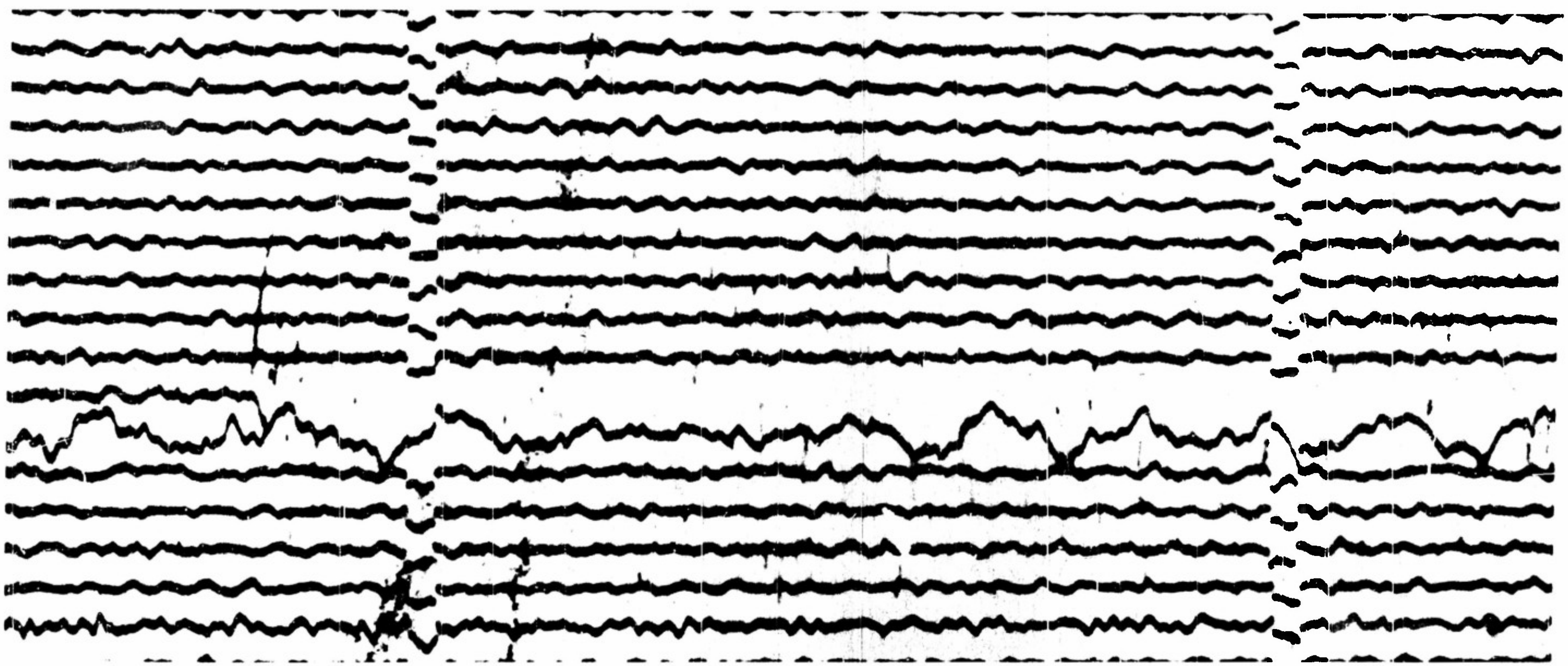
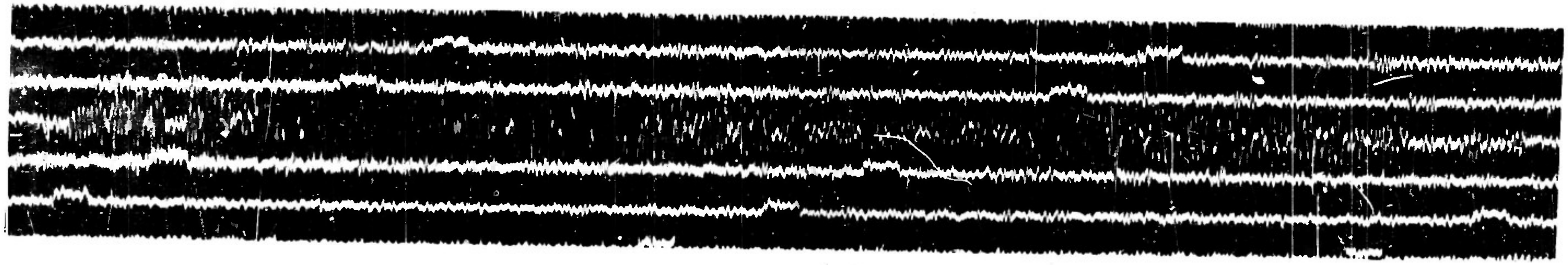


Figure III - B

San Juan P Phase of Earthquake 9



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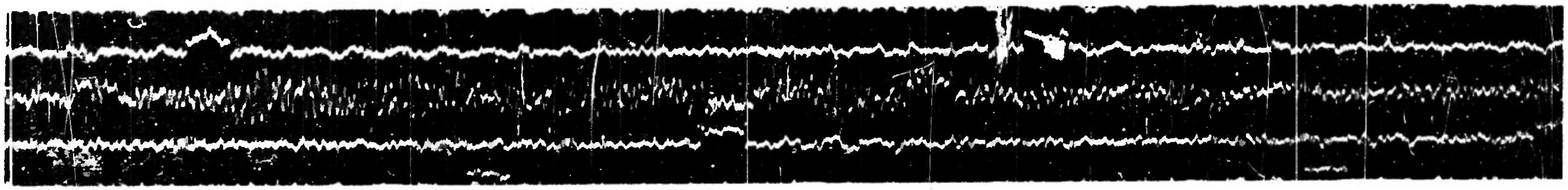
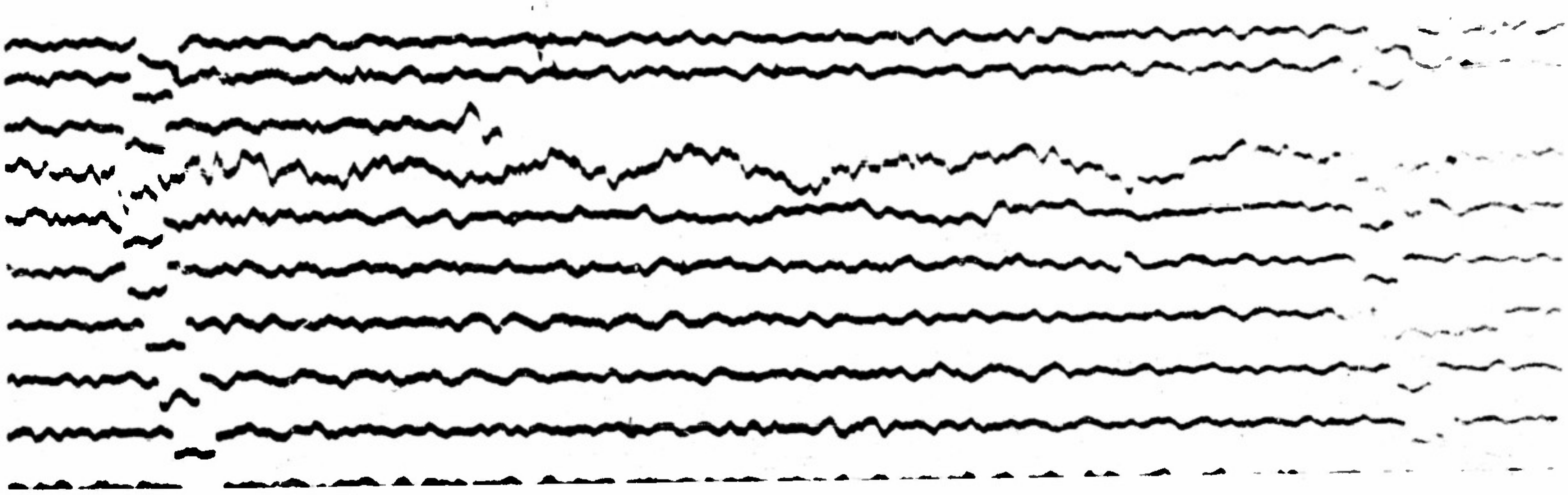


B

Figure IV

A Bermuda T Phase of Earthquake 17

B Bermuda T Phase of Earthquake 9



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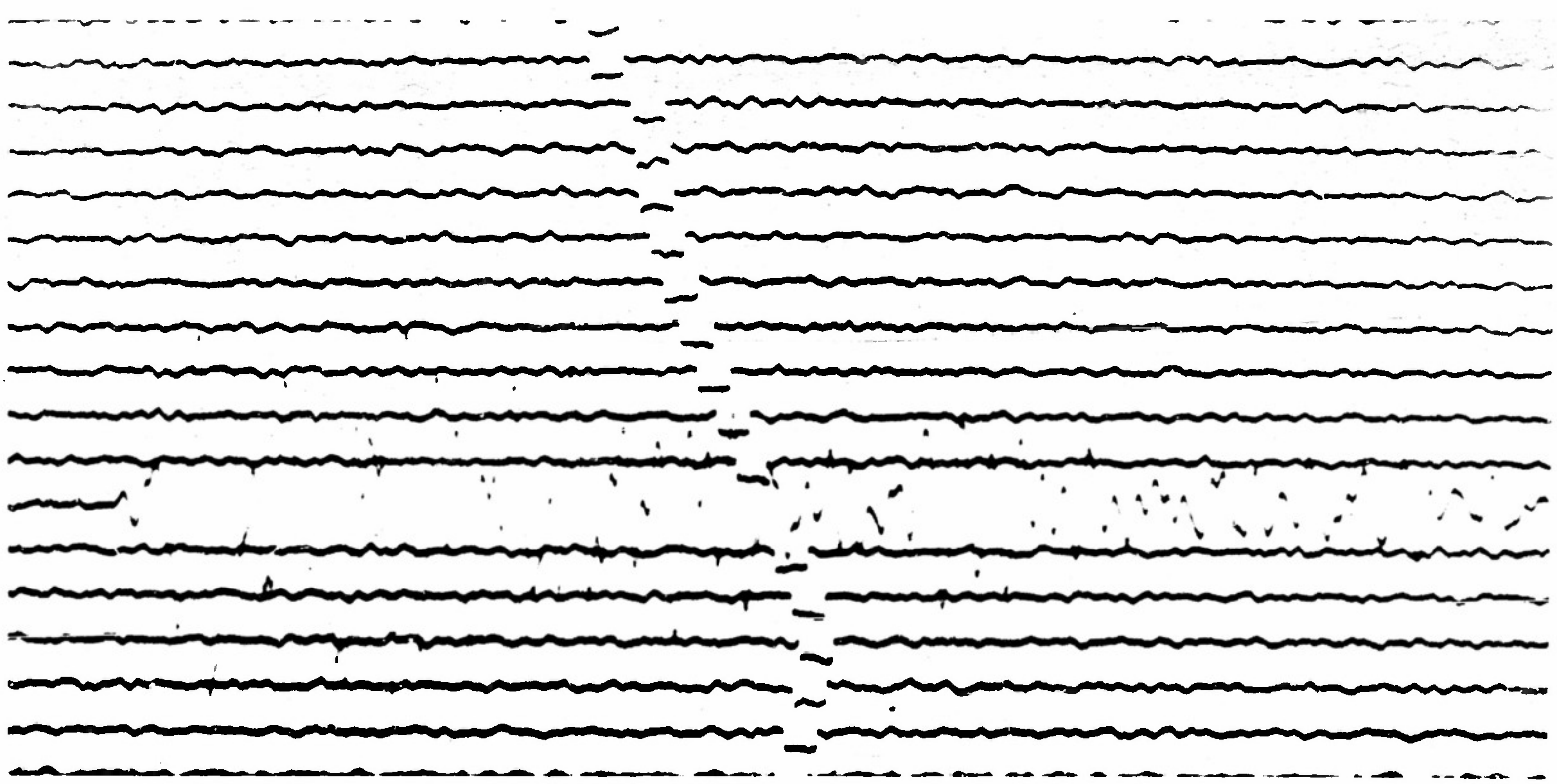

B

Figure V

A San Juan P Phase of Earthquake 16

B San Juan P Phase of Earthquake 18

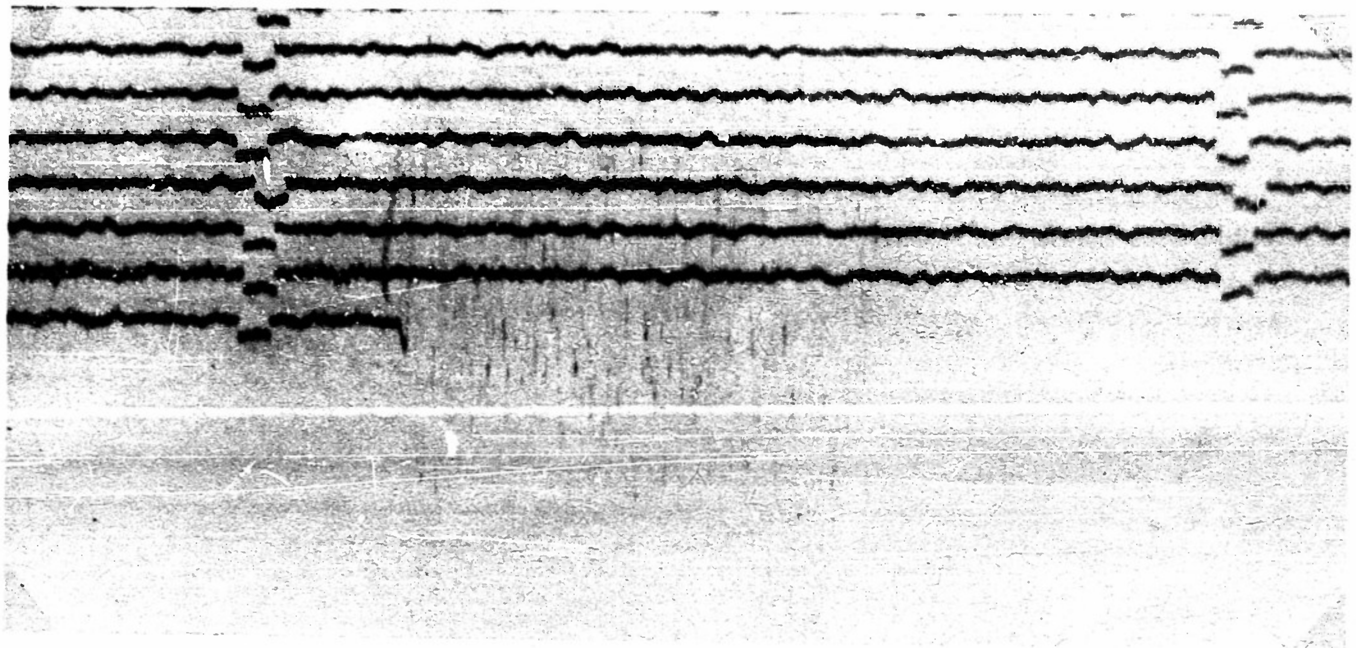

Figure VI

San Juan P Phase of Earthquake 24

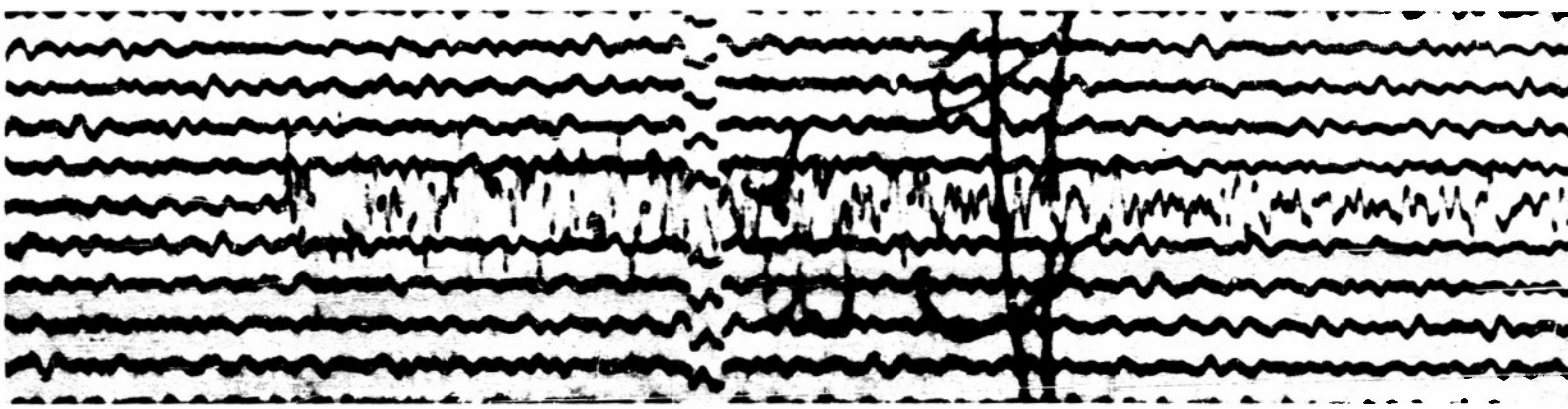

Figure VII

San Juan P Phase of Earthquake 13